Lifting and Transport of Saharan Dust

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Abstract. Tropospheric aerosols have a significant influence on climate and have been recognised by the Intergovernmental Panel on Climate Change as the biggest source of uncertainty in understanding future climate, yet the factors controlling their spatial distribution remain unclear. Despite new observations from the UK ATSR instruments and the MODIS and MISR instruments (on NASA's Terra satellite) there are still open questions about aerosol sources, sinks, microphysical properties and the aerosol vertical distribution.

A three-dimensional dust lifting and transport model, using meteorological fields from ECMWF analyses, is used to compare predicted mineral dust loading over the Sahara with observations of optical depth from AERONET, SEVIRI, AATSR, and MISR. The model is used to investigate the sensitivity of the predicted aerosol profiles to variations in model parameters, including desert dust emission. Estimates of yearly emissions, and monthly depositions and mass fluxes into the Atlantic are presented.

Large scale dust storms have been observed coming off the Sahara desert [*Slingo et al.*, 2006] by satellite instruments such as SEVIRI, but these instruments cannot accurately assess the spatial distribution of aerosol particle sizes. The aim of the current work is to predict the transport of desert aerosol using meteorological and soil data.

Emission

The 3D model is driven by meteorological data from the European Centre for Medium-range Weather Forecasting (ECMWF) at a resolution of 1.125°), and by soil data (*Laurent et al.*, 2008) from the Laboratoire Interuniversitaire des Systèmes Atmosphériques (LISA), which provides an estimate of the soil size distribution, surface roughness lengths, and other surface properties, at a resolution of 0.25°.

Saltation and *sand-blasting* are the key mechanisms for mobilising and emitting dust particles from the surface: saltation is a transport mechanism in which sand particles are ejected by impact of other particles, and when they strike the surface again they eject (sand-blast) more particles. The emission flux is described by *Marticorena and Bergametti* (1995) as being linearly proportional (by the *sand-blasting efficiency* α) to the saltation flux, G:

$$G = E\frac{\rho_a}{g}u^{*3}\int_{D_p}^{\infty}\left(1+\frac{u_t^*}{u^*}\right)\left(1-\frac{u_t^{*2}}{u^{*2}}\right)dS_{rel}(D_p)dD_p.$$

E is the fraction of erodible surface, ρ_a is the air density, u^* is the wind friction velocity, u_t is the threshold friction velocity for particles of size D_p, and dS_{rel} relates to the size distribution. There is no emission from the Sahara when the wind speed is less than ~ 6.5 m/s. The larger particles (radii > 10 µm) quickly drop back to the surface (so they are not included in this formulation), while finer particles (typically less than 1-2 µm) can be transported to higher altitudes (up to 8 km or so), and further.

The main source regions for mineral dust are those areas with a large amount of exposed fine particles. 'Hot spots' are regions which have been identified as particularly strong sources, these are often dried lake beds or seasonal streams, which are regularly fed by fine silt particles, but which are dry, so that the particles do not stick to the surface as much as when it is wet.

The *roughness length* of the surface is a length scale which indicates the roughness of the surface. Higher roughness elements cause a stronger wind friction velocity, since the surface disrupts the wind more. However, higher roughness elements (eg. rocks, mountains) also shield the erodible areas from the wind (giving rise to E in the saltation flux). This *drag partitioning* decreases the wind stress over the erodible elements; in the emission scheme this translates to an increase in the threshold friction velocity. Hence the Tibesti mountains (Chad), the Hoggar massif (Algeria), and the Atlas mountains along the coast of north-west Africa do not emit dust, while the more low-lying areas of the desert do.

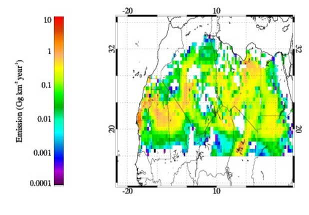


Figure 1: Total dust emissions from the Sahara in 2006.

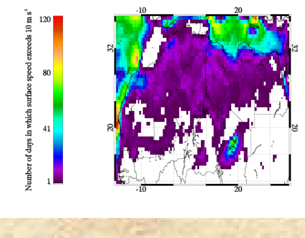


Figure 2: Frequency of high wind-speed events in 2006.

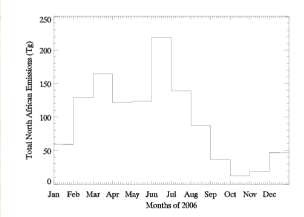


Figure 3: Monthly total dust emissions (Tg), 2006. Yearly total is 1158 Tg.

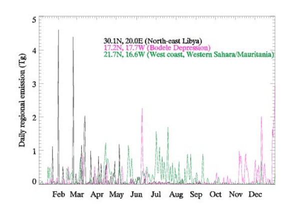


Figure 4: Time-series of emissions from 3 source regions in the Sahara, 2006.

Figure 5- Time-series of total mass loading over the Sahara, March 2006.

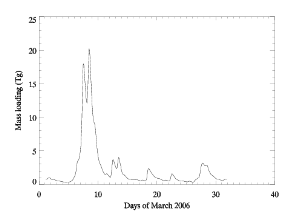


Figure 6: Daily dust flux into the Atlantic, March 2006. The 8th March is the day that a large pan-Saharan dust event peaked. During the month, 4.95 Tg of dust left the coast of West Africa.

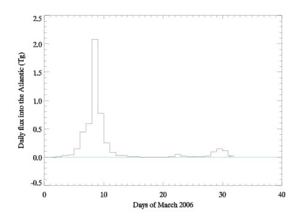
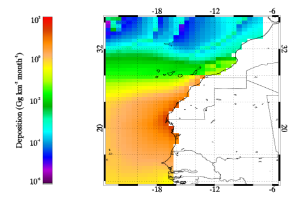


Figure 7- Dust deposition into the Atlantic, March 2006. The total was 3.5 Tg.



Transport

Processes included in the model are advection, diffusion, gravitational settling, turbulent deposition, and wet deposition. Output from the transport model is a size distribution of particle concentrations, in 3 space dimensions and 1 time dimension. The domain is pan-Saharan, to an altitude of ~ 10 km. Optical depth over each column can also be inferred, using Mie Theory: the assumed refractive index is 1.5 + 0.004i [Munoz et al., 2007].

Observations and Data Assimilation

In order to validate the model results, the predicted optical depth can be compared against observations of optical depth. Instruments currently used include the AERONET network of ground-based sun photometers (21 within the domain), which is used to validate the model and provide an estimate of model error. Data assimilation has been carried out using the Dust Regional Intercomparison project (DRI- data from Elisa Carboni and the DRI team), nudging the model results to the satellite observations. The DRI data includes observations from AATSR, AIRS, MERIS, MISR, MODIS, OMI, POLDER, SeaWiFs and SEVIRI.

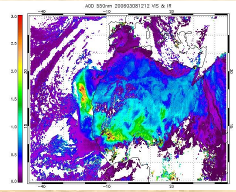


Figure 8: SEVIRI AOD at 550 nm from the Oxford- RAL retrieval algorithm (Elisa Carboni, private communication) on 8/3/2006.

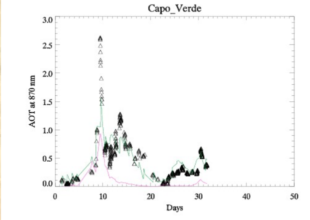


Figure 9: Inter-comparison between AERONET data (white triangles) from the Capo Verde site in the Cape Verde Islands (22.94°W, 16.73°N) and the corresponding model and assimilated model optical depth at 870 nm (pink and green lines). AERONET data courtesy of NASA (PI of the site is Didier Tanré).

References

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